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RESEARCH ON VIBRATORY-OUTPUT ANGULAR MOTION SENSORS

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by

Robert W. Rasche
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1. GENERAL

This status report covers research carried out by personnel of the Electronic Systems Laboratory, Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge 39, Massachusetts during the period 1 December 1962 through 31 May 1963 under Research Grant No. NsG-149-61 of the National Aeronautics and Space Administration. Work in the areas of the double-modulated tuning fork rate gyro and of feedback suppression of cross-coupled signals has continued. Tentative results have been favorable to the double modulation technique, but conclusive evaluation of the method has not been made. The following sections briefly describe the results to date, indicate problems which have arisen and the status of their solution, and the financial status of the project.

2. SUMMARY OF CONTINUED RESEARCH

a. Double-Modulated Tuning Fork Gyro

The major research effort was directed toward evaluation of the double modulation principle as applied to a tuning fork gyro configuration.*[1] An

* Superscripts refer to numbered items in the List of References.

evaluation was performed in September 1962. Without double modulation a noise level of about 700 eru (earth rate units) was obtained. This noise level was reduced to 90 eru through the use of double modulation. Zero rate drift without double modulation was so extreme that gravity effects could not be evaluated. Continued effort since then has been directed toward providing a more meaningful experiment which will indicate conservative values of improvement. Rework (see Ref. 2) of the experiment fixture and associated electronics and improvements to the gyro package per se have progressed during this reporting period. On 12 April 1963 data taken without double modulation indicated a reduction in output noise from the previous 700 eru to 10 eru. Zero rate drift while quite pronounced was entirely measurable and seemed primarily related to temperature variations. A d-c drive motor and associated control circuitry for providing double modulation has been developed. This system can operate continuously over a range from six to sixty cycles per second and maintain constant phase with respect to a reference oscillator to within one mechanical degree. This variable speed feature allows evaluation of the double modulation technique over a wide range of spin frequencies.

Rigidity of the experiment fixture has been significantly increased by moving support bearings closer together and by providing more substantial bearing support plates rigidly connected by a tubular cage.

Four access holes were cut in the cage. These slots have resulted in a change in effective capacitance with rotation which is reflected in the vibration pick-up output. An all d-c excitation of the capacitance bridge used to detect torsional vibrations due to applied angular rates was experimentally evaluated. While such excitation offers some advantages, in the system configuration constructed for experimental work the d-c bridge did not compare favorably with the r-f bridge and has been abandoned.

Double modulation data were obtained and indicated an average zero rate variation at least fifteen times less than that obtained without double modulation under similar conditions. In particular, double modulation appears to appreciably reduce the temperature sensitivity of the device by at least an order of magnitude.

Reliability of operation is currently the major problem preventing an exhaustive evaluation of operation of the tuning fork gyro with and without double modulation. The oscillator circuit which excites the capacitance bridge has required continued modification and trouble-shooting to improve performance in the presence of vibration and appreciable centrifugal forces.

The tuning fork package and electronics have been modified to provide a more constant phase reference signal for subsequent signal demodulation and a significant improvement in performance has been obtained. Electronics external from the rotating assembly have been refined and appear to be entirely adequate. All pertinent circuits have been reworked to accommodate all double modulation frequencies of interest without adjustment.

Computer time on the IBM 7090 Computer of the MIT Computation Center has been obtained and programming of data processing routines has been started.

A number of unanticipated departures from expected gyro behavior have occurred. Subsequent investigations of these have resulted in increased knowledge and have contributed to a greater understanding of the device, both in general and with respect to the particular experimental configuration in use.

In summation, all experimental results have indicated substantial performance improvement due to double modulation. Problems which have arisen have been associated almost entirely with reliability of the experiment and are not inherently associated with double modulation. Current efforts are directed toward obtaining longer term reliability.

b. Feedback Suppression of Cross-Coupled Signals

A doctorial thesis proposal by Richard W. Bush entitled "Feedback Suppression of Cross-Coupled Signals in Vibratory Gyroscopes", has been prepared and submitted. The following is the abstract of that proposal:

"A review of previous work on suppressed carrier amplitude modulated control systems and also vibratory gyroscopes is presented first in this proposal. The filtering problem associated with vibratory gyroscopes (especially those employing double modulation) is chosen as the main topic for the thesis research.

The thesis will develop a statistical filter theory for suppressed carrier amplitude modulated control systems in which the gyroscope problem will be used as a case study. Limitations imposed by modulation, fixed elements in the system, saturation constraints and carrier frequency instability will be considered. In order to investigate the practical applicability of the derived theory, the vibratory gyroscope filtering will be experimentally evaluated. As a result of both the theoretical and experimental work, the performance limitations of vibratory gyroscopes employing double modulation will be determined and the usefullness of the filter theory tested."

3. PROJECT DOCUMENT STATUS

Two publications were released during this reporting period. They were: Whitman, J.G., Capacitive Transducers for Narrow-Band Vibratory Displacements, MIT Report ESL-R-153; and Whitman, J.G., and Swerdlow, R., A Vibratory Acoustic Gyroscope, MIT Technical Memo ESL-TM-162.

In addition to these technical publications, an outline for continuation of the research entitled, Proposal for Research on Vibratory-Output Angular Motion Sensors, Preliminary Issue, and dated 18 April 1963 was submitted to NASA on a preliminary issue basis. An enclosure to this proposal was an extract from a doctoral thesis proposal by R.W. Bush. This extract was entitled "Review of Research on Vibratory Gyroscopes Employing Double Modulation" and provides background to the current research effort.

4. [redacted]

5. ANTICIPATED FUTURE RESEARCH

Future research will be directed towards obtaining conclusive experimental evaluation of the double modulation technique and continuing work in the area of feedback suppression of cross-coupled signals.

6. REFERENCES

1. Alme, R., Bush, R., et al, Research on Vibratory-Output Angular Motion Sensors, (Second Status Report) Report ESL-SR-144, Electronic Systems Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, June 1962.

2. Rasche, R.W., Research on Vibratory-Output Angular Motion Sensors, (Third Status Report), Report ESL-SR-158, Electronic Systems Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.